Role of knowledge and policies as drivers for low-energy housing: case studies from the United Kingdom

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*Title Page

Role of knowledge and policies as drivers for low-energy housing: Case studies from the United Kingdom

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Abstract

Addressing housing-related energy consumption and emissions is a challenge in many countries. Low-energy housing, e.g. whole house retrofits and zero-energy new houses, is still rare in the United Kingdom, yet very much required to reduce emissions. This paper contributes to research on low-energy housing by adding new empirical material through analysing how specific drivers linked to knowledge, public policy and intermediary actors can influence successful projects. Based on in-depth case study research of both existing and new built low-energy housing projects in Brighton, United Kingdom (UK), we show that in addition to motivations to improve existing housing conditions, knowledge and available skills of householders and project participants, and both local and national policies, drive such projects. We also find that intermediaries inspire projects, connect different actors and facilitate learning between projects. Intermediaries are important for advancing projects through local actors and knowledge-networks, especially at a time when national policy support for low-energy housing remains limited and a wider transition to low-energy housing is not complete.

Keywords

Housing; buildings; energy efficiency; low-energy; retrofit; intermediaries

1 Introduction

One key challenge facing Europe, over the next 30 years, is reducing energy use in the built environment (e.g. Meeus et al., 2012). Buildings as a whole, in construction, use, and demolition, consume 40% of energy globally (Yeatts et al., 2016). The residential housing sector is the third largest energy consumer, accounting for 27% of the world's total energy consumption (Nejat et al., 2015). The building sector has been falling short on achieving climate commitments, with energy consumption growing by 5% between 2010 and 2016 (IEA, 2017). Improving the conditions of existing housing and ensuring that new houses are near zero-energy are important for mitigating emissions and adapting to future climate trends. Without urgent measures, building related greenhouse gas (GHG) emissions could rise by 21% by 2020 (Yeatts et al., 2016).

While many technologies and tools already exist to build new low-energy houses and retrofit existing houses, the uptake of such measures in many countries is not widespread (Yeatts et al., 2016; see Section 2), the United Kingdom (UK) being a case in point. We thus examine successful low-energy housing case studies in a country that has not been advancing rapidly in this front, identifying drivers that could be amplified to support the diffusion of low-energy housing in the UK. An earlier systematic review found that relatively few existing academic studies examine the drivers for innovative low-energy housing projects in Europe; in particular, academic case study research on retrofitting existing housing is lacking (Kivimaa and Martiskainen, 2018a), and studies addressing both new built and existing houses are rare.

In this paper, we analyse new and existing homes, examining key reasons that have enabled low-energy housing projects to be developed successfully. We base our research on six in-depth case studies conducted in Brighton, UK, addressing the following research questions: 1) What have been the supportive factors for the development of innovative low-energy housing projects and 2) what can we learn to stimulate a wider uptake of such projects in the UK and elsewhere? Our findings show that successful low-energy housing projects require knowledge-related drivers (including wide-ranging skills base and the ability for practical learning from other projects), specific policy support, and facilitation by intermediaries.

Section 2 provides an outline of the challenges and benefits linked to developing low-energy housing. Section 3 details the in-depth case study method. Findings are outlined in Section 4, and discussed in Section 5. Section 6 concludes.

2 Challenges and benefits related to low-energy housing

2.1 Challenges of developing low-energy housing

The challenges linked to developing low-energy housing are widely acknowledged, multifaceted and vary depending on context. *Retrofitting* often requires additional effort (Caird et al., 2008), particularly, whole house retrofits – similarly to new build – can involve several measures carried out by numerous contractors (Brown, 2018). Some buildings pose challenges due to their limiting physical forms (Galvin, 2014) or historical significance (e.g. Mazzarella, L., 2015), the latter often subject to specific planning regulations (Aste et al., 2012). Such projects also require large upfront capital costs and often have long payback times, reported in Germany (Galvin, 2014), UK (Bonfield, 2016) and Denmark (Holm et al., 2011), for example. It can be difficult to estimate the total cost of retrofits as each house is different. Retrofit projects have not always had detailed records of costs, especially if retrofitting was undertaken in stages, included do-it-yourself contributions, and external costs such as rent in temporary accommodation (Fawcett and Killip, 2014). Retrofits can cause interruptions to everyday lives, often over long periods of time (Simpson et al., 2015; see also Pettifor et al., 2015). The 'hassle factor' of having to spend time clearing a house before major retrofit works, such as loft insulation (DECC, 2013) or underfloor insulation, can start, are well reported (Simpson et al., 2015). Thus, smaller improvements often happen over a number of years, instead of a one-off whole house retrofit (Simpson et al., 2015). A major concern, in the UK especially, has been the competence of companies undertaking retrofits: "*there have been too many instances of poor quality installations being made by companies who do not have the skills, quality levels or core values required to operate* *responsibly in this market*" (Bonfield, 2016, p. 4). Poor installations can cause harm, such as damage to building structure (Bonfield, 2016).

Regarding *new build*, cost can be an issue too, as new low-energy housing can be seen to be expensive, though the overall running costs of low-energy homes are often lower than of conventional homes (Pickerill, 2016). As with retrofits, specific knowledge is required, while skills gaps have been reported as an issue (Maby and Owen, 2015). The UK construction industry has been described as a sector locked-in to certain building practices and materials (Lovell and Smith, 2010). Developing and fostering innovation in construction requires collaboration, which can have high management and coordination costs (Mlecnik, 2013). Thus, it it can be easier for housebuilders to use a narrow range of technologies to suit their existing skills and practices (Lees and Sexton, 2014). Building regulations, which require minimum energy standards for new housing, are not always complied with, as found by Evans et al. (2017) in a review of 22 countries. Even in relatively advanced countries for building energy efficiency (such as Finland), lack of sufficient implementation can be a concern (Kivimaa et al., 2017).

For both retrofit and new build, there are also challenges linked to actual energy performance (Lowe, 2000). Energy perfomance objectives set at design stage do not always realise in practice (Liang et al., 2017). New technologies require householders to learn new ways of using their house (Liddell, 2015; Walker et al., 2014), and incorrect use of technologies (e.g. mechanical ventilation systems) can cause problems (e.g. overheating) (Gupta and Gregg, 2012; Shrubsole et al., 2014). This has become a health and comfort concern, especially with a warming climate (Harlan and Ruddell, 2011).

There are also challenges linked to the multiplicity of policies and policy instruments. For example, in the UK, a large number of policy instruments has created a complex 'policy mix' (Kern et al., 2017), which may require 'translation' from actors such as architects to be effective (Fischer and Guy, 2009). In addition, challenges, such as rapidly changing policies in the UK (Kern et al., 2017), lack of resources in China (Shen et al., 2016), ineffective implementation of building energy efficiency policies in Finland (Kivimaa et al., 2017), and lack of innovation policies targeting building energy efficiency in Japan and China (Huang et al., 2016) have been identified. Policymakers thus increasingly acknowledge the importance of good implementation, and focus is shifting "*from adopting more stringent requirements to supporting implementation of existing requirements*" (Evans et al., 2017, p.388). While overall attention is, in many countries, made to improve building energy efficiency, policy challenges influence how householders take up such policies.

[Insert Table 1]

2.2 Drivers for developing low-energy housing

There are many benefits to low-energy housing. Most projects are driven by environmental values and motivations (e.g. Meeus et al., 2012; Rovers, 2014). Other drivers include comfort (e.g. Holm et al., 2011; Mlecnik 2010), lower energy costs (Friesen et al., 2012), and regulation or voluntary standards (Rovers, 2014).

Many projects have been influenced by national policy through building regulations (Quitzau et al., 2012), subsidies (Pässilä et al., 2016), R&D programmes (Sunikka-Blank et al., 2012) and innovative competitions (Heiskanen and Lovio, 2010). Local authorities too can drive such projects within their own building stock (Castán Broto, 2012), through energy managers (Lovell, 2007) or by planning officials supporting others (Holm et al., 2011). Some local authorities have posed tighter building requirements in new exemplary areas (Holm et al., 2011). However, this is not possible in many countries, including the UK, where local authorities cannot go beyond national building regulations. Many innovative low-energy housing projects nevertheless take place without explicit national policy influence (Holm et al., 2011; Lovell, 2007; Mlecnik, 2010) but with lesser chances of mainstreaming.

Motivations to develop low-energy housing can arise from customer demand (Ozorhon, 2013), as for some, having a well-designed house with low-energy features is an attractive quality (Brunsgaard et al., 2012), and for others can mean higher social prestige (Mlecnik, 2010). In a review of European low-energy housing projects, in nine out of 40 cases, design featured as a specific driver (Kivimaa and Martiskainen, 2018a), with aesthetics, desired space, flexibility and historical preservation playing a part. Design was important especially when planning low-energy retrofits of historical or heritage buildings (Harrestrup and Svendsen, 2015).

Low-energy housing can also bring potential health benefits as houses with better energy efficiency and adequate ventilation can improve indoor air quality (Chenari et al., 2016). However, much of the marketing for low-energy housing, especially in the UK, has largely focused on highlighting financial savings, rather than improved comfort and wellbeing (Rosenow and Eyre, 2016). Research has shown for example the benefits of energy efficiency retrofits and improved housing conditions to health improvement in the US (Ahrentzen et al., 2016), while reduced stress levels were reported amongst residents receiving energy efficiency measures in the UK (Gilbertson et al., 2012). However, low-energy retrofits and new houses need to be completed to a high standard to ensure that indoor air quality improves, rather than worsens, as a result (Bonfield, 2016). Improving the quality of houses can also improve the quality of life (Ozorhon, 2013), and help address social equality issues such as fuel poverty and inability to maintain a comfortable indoor temperature (e.g. Bouzarovski and Petrova, 2015).

On a wider scale, low-energy housing can bring co-benefits between emissions reductions, improved air quality and health, and "*the delivery of a local co-benefit along with the climate co-benefit can help in engaging policy and decision-makers to take action for climate change mitigation*" (Balaban and Puppim de Oliveira, 2017, p. S69). Despite the potential benefits, the number of low-energy housing remains limited in the UK.

[Insert Table 2]

2.3 Low-energy housing in the UK

The UK's existing housing stock is in urgent need of improvement, while the rate of new build houses remains low. The country's residential sector, comprising around 27.6 million houses, contributed approximately 13% of UK's greenhouse gas (GHG) emissions in 2015[1] (BEIS, 2018). The UK has a legal duty to reduce GHG emissions by 80% by 2050 under the Climate Change Act 2008. This means urgent action in all areas of society, including housing. However, following the 2008 global financial crash and subsequent austerity measures, climate change has become less important in the UK's political agenda (Gillard, 2016), affecting government policy. Until 2015, the UK had a mix of policies supporting the low-energy housing transition (Kern et al., 2017), but key policy objectives were removed in 2015; including the aspiration for zero-carbon new houses and support for the able-to-pay households to undertake energy efficiency improvements (Rosenow and Eyre, 2016). The 2008 financial crisis affected the availability of mortgages (Martin, 2011) and impacted negatively on the construction sector, resulting in a further drop of new built houses (Payne, 2015) that had already been decreasing since 1980 (impacted by, for example, the early 1990s recession and subsequent housing crisis (Gentle et al., 1994). In 2015, 152,440 new houses were built, a 40% reduction compared to 1980 (ONS, 2016). Furthermore, a 'Living Home Standard' developed by UK charity Shelter and subsequent survey of the UK public found that four in ten existing UK houses were not considered to be up to standard regards to decent conditions, space, affordability and neighbourhood (Shelter, 2016). The UK also has high incidences of fuel poverty (Renovate Europe, 2017), with over 4 million households (15%) affected (NEA, 2018), and cold houses have been shown to have detrimental health impacts (Marmot Review Team, 2011).

Despite a wealth of experience and decades of local and national policies addressing low-energy housing in the UK (Kivimaa and Martiskainen, 2018b), such housing remains limited. The main databases, the Low Energy Buildings Database (LEBD, 2017) and SuperHomes (SuperHomes, 2017), list less than 500 projects in total. In a country in which households prefer old houses with period features such as sash windows and fireplaces (HomeOwners Alliance, 2017) - yet have little incentives for retrofitting such houses - going against the grain of traditional building methods and delivering new, low-energy, houses can be especially challenging. Furthermore, the UK also lacks strong enforcement of building regulations (Evans et al., 2017). With the above in mind, we analyse exemplary low-energy housing projects, capturing the their main drivers and success factors to learn for the future.

[1] This figure includes gas consumption only, used for heating and cooking. BEIS calculations of emissions related to residential electricity use, including electricity use for heating, are included as part of power stations. Therefore, emissions from residential electricity use are calculated in the energy supply sector rather than the residential sector (BEIS, 2018). Approximately 85% of housing in the UK is connected to the gas network.

3 Method

We base our analysis on qualitative research on the development of low-energy housing in the UK. The research included a review of relevant academic/policy literature and expert interviews leading to a 15,000-word narrative of the sector's development, and an in-depth case study analysis of six low-energy housing projects (Figure 1).

[Insert Figure 1]

The literature review was used to identify key issues affecting the sector. Scoping interviews with six experts (local and national policy makers, housing associations, researchers and not-for-profit practitioners) were used to inform: 1) the status of innovation in the UK low-energy housing sector; 2) details of actors that are facilitating innovation in the sector or helping specific innovation projects; 3) examples of innovative projects; 4) information on any guidelines; and 5) details of networks active in the sector.

An in-depth case study approach (cf. Flyvbjerg, 2011) was used to analyse selected low-energy housing projects, located in one political and geographical context to be able to better compare the drivers in each case. The city of Brighton and Hove was selected based on the following criteria: 1) prominence as an environmentally-aware city (it has for example the only Green MP in the UK); 2) location as a showcase for low-energy houses through an annual Eco Open Houses event; 3) high housing-related carbon emissions (40% compared to national average of 31% (Brighton and Hove City Council, 2017)) and 4) a high proportion of older buildings (39.8% of the housing was built before 1919 (Brighton and Hove City Council, 2017), i.e. before building regulations), protected through conservation areas with planning restrictions. The scoping interviews and the Eco Open Houses information guided case selection: six projects were chosen (three new built and three retrofit) representing different building types (e.g. apartment building, terraced house, detached house), ownership forms (e.g. owned outright, owned with a mortgage, private rented and rented from a social housing provider) and building processes (e.g. large commercial developer, housing co-operative, private house owners, and self-builder). The selected cases can be considered low-energy compared to the UK's average homes. See Table 3 and Appendix A (technical summary[2]) for details of the cases.

[Insert Table 3]

[2] Detailed case histories are available from the Centre on Innovation and Energy Demand at: http://www.cied.ac.uk/project/low-energy-housing-innovations-and-the-role-of-intermediaries-lehii/ (Accessed 18.05.2018)

Case study data were collected via 16 semi-structured interviews (e.g. Hakim, 2000), either by face-to-face (n=13), over the phone (n=3) or via email (n=1). Each project involved 1-7 interviews, depending on the number of core people involved. Interview questions focused on: 1) interviewee's involvement in the project and any other key actors; 2) vision and expectations for the project; 3) resources required and how those were provided (e.g. skills, funding, networks etc.); 4) problems occurred; 5) influence of public policy; 6) importance of building energy efficiency in the project; and 7) key learning. Interview data were used to analyse each project in relation to early development and planning (e.g. motive and initiation, knowledge gathering, acquiring planning permission), building process (e.g. creating project teams and partnerships, constructing the project) and dissemination of learnt experience (e.g. project dissemination, acting as an example to others, contribution to learning). All but one e-mail interview were digitally recorded and transcribed. Background documents, site visits to each project and, in one case (One Brighton), an attendance of an on-site learning tour organised by UK Green Building Council (UK-GBC), were used as additional materials. Detailed case histories of each project (16-31 pages each; following Douthwaite and Ashby, 2005) were written and sent to interviewees to check. The analysis is based on two researchers coding the case histories thematically (Braun and Clarke, 2006), reflecting on key issues relevant to the development of the projects.

4 Findings

This section summarises our findings on the key drivers, presented around the following themes: motivation to develop projects, the influence of skills and knowledge base, and the impact of public policy (summarised in Table 4 and discussed below).

[Insert Table 4]

4.1 Motivations to develop projects

Motivations to develop the projects included *energy and environmental* (e.g. saving energy, climate change), *financial* (e.g. saving money, a profitable project), *design* (e.g. developing a house that functions well and looks good), *comfort* (e.g. improved thermal comfort) and *knowledge development* (e.g. developing new ideas, trying out new technologies or techniques). These confirm also findings by earlier research (e.g. Friesen et al., 2012, Holm et al., 2011, Meeus et al., 201, Mlecnik 2010, Rovers, 2014). Of these, we examine *design* and *comfort* in more detail. The owners of new builds Grantham Road and Hartington Road wanted to create houses that were appealing, sustainable, and well-functioning. As graphic designers, the owners of Grantham Road had a strong focus on aesthetics, while the owner of Hartington Road had experience in sustainable design structures and interest in architecture. In One Brighton, One Planet Living (see Section 4.2.2 for details) was a new design benchmark also for the architectural team. There were no strong design drivers for the retrofit cases, but as highlighted in Section 2.1, historical buildings often have limitations to how much they can be altered. In all the retrofit projects, *comfort* was an important motive. All three retrofit houses had cold and damp rooms, and they were hard to keep warm due to inefficient windows and walls. Also, in the new builds, the owners of Grantham Road were also looking forward to moving from their old and cold Victorian-era house to their new low-energy house, expecting better comfort. The Hartington Road owner had lived for years in draughty and cold rental accommodation, and wanted to build a comfortable home. As only one case, One Brighton, had detailed post-occupancy evaluation, interviewees for the other five cases reported on their experience anecdotally. In all of the retrofit cases, improved thermal comfort was reported with warmer and less draughty rooms. There was case specific variation, however, in whether improved thermal comfort led the occupants to realise cost savings through reduced energy bills or whether they actually increased room temperature, therefore not realising potential energy cost savings (e.g. Chitnis and Sorrell (2015) on the rebound effect).

4.2 Skills and knowledge base as drivers

Our findings show that *inspiration and learning from intermediaries* was important, as was learning from *previously developed projects*. While, the cases had a mixed level of prior knowledge and skills, the participants' *pre-existing skills* in other areas added specific value in two new build cases (Hartington Road and Grantham Road).

4.2.1 Inspiration and learning from intermediaries

The owners of new build Grantham Road and the retrofit Wichelo Place, and the project initiator in the retrofit The Nook, were influenced by the Centre on Alternative Technology (CAT), a prominent pioneer of renewable energy and sustainable building materials in the UK (Pickerill, 2016). The owners of Grantham Road had visited CAT during a family holiday in the 1970s being impressed by what they saw, while the owner of Wichelo Place and the initiator of The Nook, undertook environmental masters' courses at CAT providing skills in sustainable housing. CAT effectively acted as a knowledge intermediary (Martiskainen and Kivimaa, 2018). The owners of Grantham Road and Hartington Road particularly mentioned Eco Open Houses (Eco Open Houses, 2015; see also Berry et al., 2014) as a source of information and practical examples. Eco Open Houses ran in 2008 and during 2010-2015 in Brighton, showcasing sustainable houses to the public to visit. The event provided "*a neutral space for local learning*" without advocating specific technological solutions (Martiskainen and Kivimaa, 2018, p.26). All of the six cases took part in Eco Open Houses once completed, contributing to learning by providing an opportunity for others to see their projects.

4.2.2 Learning from previously developed housing projects

Developing low-energy housing is a complicated process, requiring specific knowledge and skills or, in minimum, the ability to acquire new knowledge and skills. In the new build One Brighton, the main developer Bioregional had first-hand experience of developing and building sustainable housing projects, having completed an influential sustainable housing development BedZED in 2002. Experience from BedZED regarding *technology* (building fabric and renewable energy), *lifestyle* (car-free development), *finance* (developing a profitable project) and *performance* (post-occupancy evaluation) were applied. For example, BedZED had not been cost-effective, so to achieve that in One Brighton, technological choices were simplified and the development had a stronger focus on incorporating a 'whole lifestyle' approach. One Brighton became the first 'One Planet Living' development in the UK – centred on key sustainability objectives regarding energy, waste and lifestyle (for details, see Bioregional, 2018). Bioregional also used a Sustainability Integrator (as a project intermediary (Martiskainen and Kivimaa, 2018)) who ensured that One Planet Living principles were adhered to by all partners throughout the construction process.

In the new build Grantham Road, the building company had previously constructed a low-energy house in Brighton that was showcased during Eco Open Houses, and for which the builder received a national award. They were able to draw on that experience in building Grantham Road (their architect did not initially have such expertise).

In the retrofit The Nook, the project initiator had been involved in low-energy buildings since 2003. He had managed an award-winning off-grid housing project Earthship Brighton, publishing a book on it. In addition to his CAT master's degree, he was a Certified Passivhaus Designer and a member of a local building co-operative of small businesses, an arrangement where companies with different skills bases could come together to deliver retrofits. Through the co-op, he was also involved in the government-funded Green Deal Pioneer Places (GDPP) programme (from which the Southampton Street case benefited). The Nook's initiator had to, however, adapt his previous experience. For example, while the Earthship had been a new build, The Nook added a new aspect: people living in the house while retrofit works were being undertaken. This was disruptive to the occupants and those doing the retrofit works and required changes such as moving the occupants out during the most disruptive part (e.g. floor insulation).

Previous experience of developing low-energy housing was beneficial in most of the cases. However, they all also required continued learning, skills acquisition and the ability to adjust as the projects progressed, given that each building project is different and represents a different set of challenges.

4.2.3 Using pre-existing skills when there is no direct project experience

In the new build cases of Hartington Road and Grantham Road, the owners and architect respectively did not have direct experience from previous low-energy housing projects. However, they had useful pre-existing skills. The owner of Hartington Road was highly skilled in engineering and design, had previous experience working with wood and owned a company specialising in low-energy lighting. While Grantham Road's owners were not very knowledgeable about low-energy solutions, they, as graphic designers, worked closely with the architect, influencing the final designs. The owner of Wichelo Place retrofit combined his engineering skills with his CAT masters' studies, gaining an ability to choose materials for his retrofit. These examples show how the ability to transfer and apply pre-existing skills was useful in decision making processes related to design and materials.

4.3 Public policy influence

Many projects benefitted from supportive *national* or *local* public policy. Five out of six cases were influenced by national policy (two new builds except Hartington Road and all three retrofits), and benefitted from local policy support (excluding the Grantham Road new build). The policy influence can be divided into arising from general goals and supportive policy context for low-energy houses, specific policy instruments, and helpful individuals.

4.3.1 National policy

During 2007-2010, when four of the projects were initiated (new builds Hartington Road and One Brighton, and retrofits The Nook and Wichelo Place), were peak time for low-energy housing policy in the UK. While Bioregional developed One Brighton (initiated in 2007) despite policy, the construction company involved was influenced by the government's zero-carbon objectives. The owner of Wichelo Place drew inspiration from national building regulations' energy efficiency requirements, even though they did not apply to retrofits. Meanwhile, national planning policy change in early 2013 reclassified external wall insulation from an extension to an improvement, enabling a relatively quick development of the Southampton Street retrofit.

More specific policy instruments influenced new build Grantham Road and retrofits Southampton Street and The Nook. The Code for Sustainable Homes, a method for rating the environmental performance of new houses in place during 2006-2015, applied in the Grantham Road case. The house was built to a site (part of the owners' old garden) regarded as a greenfield site following a policy change which changed garden sites to greenfield sites. Therefore, it needed to meet Level 5 of the Code (Level 6 included the strictest sustainability criteria), and achieved it through several measures (see Appendix A).

Two retrofit cases, Southampton Street and The Nook, benefitted from government subsidy schemes. Southampton Street was selected for Green Deal Pioneer Places (GDPP) programme, funded by the then Department for Energy and Climate Change (DECC) via local authorities. The Brighton co-operative Green Building Partnership (an intermediary between multiple participants) received £250,000 to carry out 100 assessments, and selected 10 houses for a £10,000 package of retrofit measures each. Thus, the retrofit was partly publicly funded - without it the owners would not have been able to carry out a retrofit. The Nook's project initiator (an intermediary between several low-carbon initiatives) came across Retrofit for the Future (RfF), a £17 million government innovation demonstration programme which encouraged social housing providers to collaborate with architects, designers, contractors and researchers to achieve an 80% CO_2 emission reduction via retrofits. Funding was available for 194 feasibility studies, and 86 projects were chosen to receive of up to £150,000 for actual retrofit. This covered 86% of The Nook's total retrofit costs and it became one of three projects that met RfF's emissions reduction objectives (personal communication; Technology Strategy Board, 2014). The Nook has provided ample learning to others: it was featured in a book (Baeli, 2013), shortlisted in the 2012 Retrofit Awards, and showcased in the Eco Open Houses (see also Section 4.2.1).

There were no specific national policies influencing across the cases, even in a period of strong policy. This changed to reduced national policy influence post 2015 (the building regulations still apply), while some recent calls have been made to introduce new policies to support retrofit (e.g. BEIS, 2017).

4.3.2 Local policy

The City Council of Brighton and Hove has facilitated low-energy houses through various initiatives, but the city also has several conservation areas restricting building works. The local master plan approved in 2003 for One Brighton site required meeting key sustainability principles: high density, public transport proximity, limited or no parking, and energy saving. The master plan was not initially developed for the derelict site but lobbied for successfully by a local intermediary, a community group Brighton Urban Design and Development. In terms of specific policy instruments, retrofit Wichelo Place received a local authority grant from the City Council to install solar water heating. The other projects did not receive similar grants.

Supportive individuals in the City Council's planning department were an important factor in four cases (new builds One Brighton and Hartington Road, and retrofits Southampton Street and Wichelo Place). Support from the Head of Planning was instrumental in getting the plans for the environmentally-ambitious new build One Brighton approved in 2007. In the retrofit Southampton Street, the City Council streamlined the application process for an Oversail Licence, needed for the external wall insulation going 100mm over the pavement. While the City Council's involvement was minimal for the smaller projects carried out by the owners themselves (new build Hartington Road and retrofit Wichelo Place), the Sustainability Department was very supportive in discussing material choices with the owner of Hartington Road. The City Council was also a co-applicant for funding in two retrofit projects: from the national GDPP (Southampton Street) and RfF (The Nook) programmes. Simultaneously, The Nook retrofit had issues with the local conservation officer regarding triple glazing. In new build Hartington Road and retrofit Wichelo Place, the approach of the planning department towards sustainability varied based on the individual in question, indicating a potential need for a more streamlined approach.

Overall, the cases show how public policy can positively influence low-energy houses in different ways, while some public policy influence seems to be at play in many successful projects.

5 Discussion

Our findings show that a mix of factors are required for developing successful low-energy housing in the UK: the right mixture of motivation, either pre-existing or newly acquired skills, learning from other projects and local/national policy support. While we identified *energy and environmental, financial*, *design, comfort* and *knowledge development* motives for developing low-energy housing,, these alone were not enough. Developing low-energy housing required specific supportive factors to overcome the challenges linked to low-energy housing (see Section 2.1). We next discuss our findings through three main inter-linking themes which are important factors for successful low energy housing: public policy support, designing comfortable homes, and mobilising intermediaries on the ground.

5.1 The importance of public policy support

Our findings show that supportive national or local policy was important in all cases. Regarding national policy, our findings, importantly, highlight how innovative policy instruments (e.g. Code for sustainable Homes, Green Deal Pioneer Places, Retrofit for the Future) influenced the local level of individual projects. Equally, however, projects also materialised without the direct influence of such instruments, with national building regulations for energy efficiency requirements guiding the way (cf. Quitzau et al., 2012). Almost all projects benefitted from the 'prime time' for low-energy housing, when national ambitions for sustainable buildings were strong at the highest policy level and there was abundant momentum for change.

The study also showed that there is no clear case for the same national policy instrument influencing across multiple cases in either new build or retrofit, even in a period of supportive policy making (cf. Kivimaa and Martiskainen, 2018b). This can either reflect difficulties in 'translating' policies to relevant stakeholders (cf. Fischer and Guy, 2009) or highlight that, due to the high case specific nature of the sector, multiple different policies are beneficial to address different types of homes and different situations. The UK policy situation has subsequently changed to one with reduced national policy influence (the building regulations still apply). With inadequate policy requirements for new low-energy houses, there is a danger that mainstream developers build new housing to minimum required standards, with limited low-energy or zero-carbon objectives (e.g. Greenwood et al. 2017). Calls have been made to introduce new policies to support retrofit (BEIS, 2017). Further, for example, Energiesprong in the Netherlands, which has provided large-scale retrofits guaranteeing improved energy and comfort performance, has been used as an example of what the UK could learn from other countries (Brown et al., 2018).

In terms of local policy, what remains partly unclear from these case studies is whether the support by the City Council has been dependent on supportive individuals, or if the City Council as an organisation, and its planning department, have adopted sustainability as an integrated priority in their operations. For example, in the case of The Nook, the old Victorian era building had to meet conservation area regulations, meaning a negotiating between sustainability and local conservation policy objectives with the City Council (see also Aste et al., 2012). In cities such as Brighton, which have a large number of old buildings and many with protected conservation status, the objectives of reducing energy consumption from housing and protecting heritage value requires careful balancing (e.g. Sunikka-Blank and Galvin, 2016). Cases such as The Nook and Southampton Street can act as examples of how to retrofit old homes that have architectural value and are located in protected conservation areas – but they were also challenging projects due to their location. While none of the retrofit cases had complicated physical building forms (Galvin, 2014), they nevertheless needed careful preparation, for example in the Southampton case to ensure that external wall insulation fitted with the existing street lines.

In general, our findings support previous literature on the importance of both national policy and local authority support (Lovell, 2007; Holm et al., 2011). Two retrofit projects almost fully depended on public subsidies, and thus, the achievement of financial benefits for the residents were in these cases subsidised by taxpayers. In the new build cases, the three cases represented three different financing models. In the large One Brighton development, a commercial developer provided finance for the project. Grantham Road benefited from access to equity and land through the owners' previous house – something that is not readily available for everyone. For Hartington Road, a self-build mortgage was used but just in time before the global financial crash of 2008 impacted mortgages. The different types of finance also reflect the different types of projects and life-events - e.g. in the retrofit Wichelo Place and new build Hartington Road, the owners were looking to increase living space in line with increases in family size, while Grantham Road wanted to downsize for retirement. Previous research has indicated that trigger points (EST, 2010), such as changes in family members, could be used to coincide with energy efficiency improvements. However, as previous research in the UK has shown that energy efficiency improvements are not considered as important as other life costs, such as paying off a mortgage (Wilson et al., 2013), this may make demand creation for low-energy homes challenging. Here the UK could learn from Germany where low interest loans have been successful in encouraging households to undertake retrofits (Rosenow et al. 2013), and across the EU too 'green' mortgages are being trialled[3]. There is thus a need for further research on new business models and strategies regarding how to mainstream low-energy housing to markets, so that case-specific public support is no longer needed; especially, as previous research in the UK has indicated that there is still a lack of efficient business models supporting retrofit in practice without significant public sector input (Brown, 2018).

5.2 Designing comfortable homes

Our study indicates how pre-existing skills, and interest, especially in the areas of design and engineering were transferable to low-energy building, partly also prompting the owners to take on projects that involved new solutions and new technologies for them, and even for

[3] For more details see: https://hypo.org/emf/market-initiative/emf-ecbc-energy-mortgages-initiative/ (Accessed 04.01.2019).

the UK. However, as many homeowners may not have such skills, this raises questions over how a broader scale of low-energy housing is achieved. This is where increasing focus on design and comfort as drivers for low energy housing could help. Interestingly, design issues were more prominent in our case studies compared to what an earlier systematic review has revealed (cf. Kivimaa and Martiskainen, 2018a). Having a house that was aesthetically pleasing, yet also sustainable and practical, was important for the new build projects. While design did not feature as prominently in the retrofit cases, comfort did. Incorporating a design approach - as presently attempted by the Dutch initiative Energisprong which suggests that design can be used as a sales argument to advance (pre-fabricated) low-energy houses in a broader scale (Brown et al., 2018) - and extending this beyond retrofitting buildings with historical values (cf. Harrestrup and Vedsen, 2015) to making homes more comfortable, could advance the appeal of whole house retrofit and thereby accelerate the low-energy housing transition. This would also require an increased focus on detailed post-occupancy evaluation and monitoring (see for example Gram-Hanssen, 2014), to ensure low-energy housing objectives are met in practice.

5.3 Mobilising intermediaries on the ground

Previous research has highlighted the importance of networks in transitions (Geels et al., 2018). A local informal network of actors was an important background factor for the Brighton projects, with intermediaries transferring ideas, visions and knowledge. Dedicated individuals became together formally and informally to advice on sustainable building and retrofitting. This was strengthened by inspiration from early pioneers like CAT, the Eco Open Houses events, and the supportive influence of the City Council as a participant in a range of initiatives. CAT has been described as an intermediary (Martiskainen and Kivimaa, 2018), providing a vision for low-energy housing solutions by sharing and facilitating learning.

Eco Open Houses, a locally based intermediary platform, did not only showcase projects, but enabled a formation of a local network of interested actors (both professionals and self-learners) and a build-up of a reference skills base including architects, builders and contractors. Learning from previously completed projects, whether new build or retrofit, can aid in practical issues such as finding out about different building materials suitable for the local context and finding trusted and skilled contractors (e.g. Bonfield, 2016). Eco Open Houses provided an opportunity to speak directly to those who have completed the process of building or retrofitting a low-energy house. In other words, many of the households involved in Eco Open Houses can be seen as 'user-side intermediaries' (Stewart and Hyysalo, 2008) who can help "*citizen users to reconfigure the standard technology to meet the specificities of different local contexts*" (Hyysalo et al., 2018, p.872). Similar initiatives have taken place for example in Australia where Berry et al. (2014) found that 75% of attendees to eco open home events had increased the use of sustainability principles in their homes 10 months after such a visit – indicating the success of such events. Furthermore, local networks require resources too, and without human and financial resources, events like Eco Open

Houses may struggle – as has been the case in Brighton where lack of funding has halted the event since 2015.

What seemed to be less prevalent were intermediaries that could 'translate' energy efficiency policies (cf. Fischer and Guy, 2009) to the actors in the building projects. Given the UK's complicated energy efficiency policy mix (Kern et al., 2017), a better presence of translating intermediaries might increase the impact of public policies in low-energy developments. Both The Nook and Southampton Street projects benefitted from a local individual who was scanning opportunities arising from national policy programmes.

6 Conclusions

This study analysed key drivers in the development of low-energy housing, using six projects from Brighton, United Kingdom, as case examples. Our findings show that the most important factor for successful projects was that they benefited from a mixture of support, rather than from one supportive element only. A mixture of supportive national and local policies, motivations that went beyond saving energy and emissions, and facilitation by intermediaries to share knowledge and learning from previously completed projects, all had a part to play.

Our study shows a strong connection between the influence of public policy (whether local or national) on specific low-energy housing projects, as well as shared knowledge and learning contributing to low-energy housing projects on the ground. Our findings also show that whilst coherent, clear and ambitious national policy is important in mainstreaming low-energy housing, supportive local authorities, acting as delivery arms, and supportive intermediaries, are needed to give case specific guidance and information on policies and planning. This has become very important in the UK context, which has lacked a dedicated national policy for low-energy housing since 2015. This is also important in cities which have heritage buildings (such as our cases' location Brighton) and, therefore, navigation of planning restrictions may be required. Based on our findings we make the following recommendations for a mixture of support required for low energy housing:

- Focus on design and comfort: Highlighting low-energy housing as well-designed and comfortable could achieve improved demand for low-energy houses, especially in the UK where many existing homes are of poor quality.
- Policy supporting comfortable homes: Stronger and coherent policies such as low-interest loans and 'green' mortgages could create demand for low-energy homes.
- Mobilising intermediaries on the ground: Publicly-supported local networks can provide shared learning. Intermediaries at different scales (e.g. user-side, local network, local authority, national network) sharing knowledge from completed projects are vital here, facilitating learning and providing impartial advice.
- Going beyond pre-existing skills: Low-energy housing projects require households to be able to choose the right materials and tradespeople. Tailored advice specific to each building type is needed, and public authorities could provide this advice more neutrally without commercial affiliations.

Our results indicate that without specific national and local policies to push for low-energy housing through new build and retrofit, it will be difficult to mainstream such activity. In public governance efforts, support is needed in the form of intermediaries 'translating' policy to practice, raising awareness of available opportunities, and getting project partners together through platforms such as the Eco Open Houses, through which households themselves can become user-side intermediaries and share practice-based local knowledge. There is also a need for further studies that examine which business models work best when national policy is weak, especially in terms of demand creation, project development and intermediation. Lastly, a focus on design and comfort is needed as overarching drivers for creating not only low-energy, but generally, better housing.

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The work used interviews and secondary literature as data. Due to ethical reasons, interview data cannot be made available. The secondary literature can be accessed through online sources.

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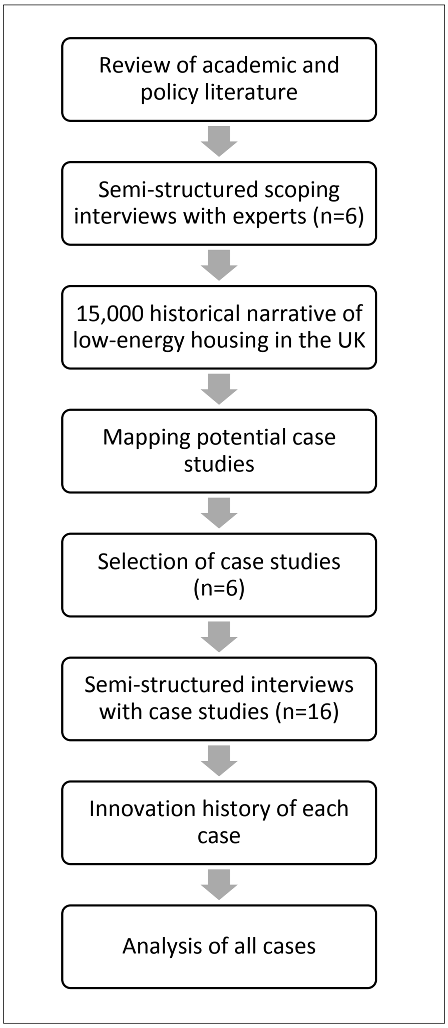
Figures

Figure 1: Research method flowchart



Source: Authors

Tables

Table 1: Summary of barriers for whole house retrofit and new build low-energy housing

Whole house retrofit	Low-energy new build
- Large upfront costs and long payback times - Complexity: several activities; numerous contractors and consultants - Limited availability of skilled and competent work force - Technical challenges - Limitations to retrofitting historically significant buildings - Disruption to residents over long-periods of time	- Large upfront costs and long payback times - Lock-in to traditional building solutions and practices - Limited availability of skilled and competent work force - Poor implementation of energy efficiency requirements in building regulations

Source: Authors

Table 2: Summary of benefits associated with low-energy housing

Benefits associated with low-energy housing (both whole house retrofit and new build)
- Reduced environmental impact - Reduced energy costs - Reduced noise from outside - Improved aesthetics - Improved indoor air quality when measures installed and used correctly

- Improved thermal comfort and wellbeing - Improved quality of life

Source: Authors

Table 3: Six low-energy housing projects chosen for in-depth analysis (based on information collected during interviews)

Case	Type of build	Key actors	Size	Construction timeline	Cost	Features	Source materials
Grantham Road	New build	Architect & builder, owners' background in design	3-bedroom detached house	Planned from 2010, construction in 2015	£450,000 (private finance)	Focus on design and sustainability Shared learning	3 interviews (face-to-face) Site visit
Hartington Road	New build	Self-builder with a background in product design and engineering	2-bedroom terraced house	Built between 2010-2012	£170,000 (self-build mortgage)	Efficient use of materials Shared learning	1 interview (face-to-face) Site visit
One Brighton	New build	Developers Bioregional, Crest Nicholson & Quantain, architect	172 apartments (of which 54 affordable)	Built between 2007-2010 after several years of planning	n/a	Based on learning from BedZED and 'One Planet Living' principles Shared learning	7 interviews (3 face-to-face, 3 phone, 1 email) Site visit Learning tour
The Nook	Retrofit	Part of 'Retrofit for the Future', owned by a housing co-operative	Large 6-bedroom detached house	Retrofit between 2009-2010	£150,000 (funded by Retrofit for the Future[1])	Located in an area with planning restrictions Post-occupancy monitoring	1 interview (face-to-face) Site visit
Southampton Street	Retrofit	Part of 'Green Deal Pioneer Places' programme	3-bedroom terraced house	Retrofit in 2013	£10,000 (funded by Green Deal Pioneer Places[2])	Located in an area with planning restrictions	4 interviews (face-to-face) Site visit
Wichelo Place	Retrofit		4-bedroom terraced house	Retrofit between 2008-2009	£35,000 (private finance and local authority grant)	Early pioneer of novel technologies Shared learning	1 interview (face-to-face) Site visit

Source: Authors

[1] See Technology Strategy Board (2014)

[2] See Section 4.3.1

Table 4: Summary of findings in relation to key drivers

Driver / influence	Theme	Empirical example
Motivation to develop projects	Energy and environment	Build a low-energy house (*Grantham Road, Hartington Road, One Brighton*) Improve energy efficiency (*The Nook, Southampton Street, Wichelo Place*) Address climate change (*all cases*)
	Finance	Achieve lower energy bills (*all cases*) Develop a profitable low-energy housing project (*One Brighton*)
	Design	Develop a house that functions well and looks good (*Grantham Road, Hartington Road*)
	Comfort	Improve thermal comfort (*Grantham Road, The Nook, Southampton Street, Wichelo Place*)
	Knowledge development	Test out new technology (*One Brighton, Wichelo Place, Hartington Road*)
Skills and knowledge base	Inspiration and learning from intermediaries	Learn from pioneers such as Centre for Alternatively Technology (*Grantham Road, The Nook, Wichelo Place*) Learn from Eco Open Houses (*Grantham Road, Hartington Road*)
	Learning from previous projects	Experience of developing previous low-energy housing projects (*Grantham Road*, *One Brighton, The Nook, Southampton Street*)
	Pre-existing skills	Transfer previous skills (e.g. design/engineering) to project when no previous low-energy housing experience (*Grantham Road, Hartington Road, Wichelo Place*)
Public policy influence	National policy	Government objective to deliver zero carbon houses (*One Brighton*) Building regulations (*Wichelo Place even though not required for retrofits*) National planning policy (*Southampton Street*) Energy efficiency policy instruments (e.g. voluntary building code, government subsidies, government innovation programme) (*Grantham Road, Southampton Street, The Nook*)
	Local policy	Local planning sustainability requirements (*One Brighton*) Staff at local planning office providing support on sustainability aspects (*Hartington Place, One Brighton, Southampton Street, Wichelo Place*)

Appendix A: Technical summary

Table A1: Technical summery of cases

Case	Description	Technical features	Energy performance
Grantham Road	- Detached house - 3 bedrooms - $120m^2$ - New build in 2015	**Building fabric and windows** - Walls: Lower ground floor has cavity block walls with 100mm insulation infill (u value $0.21W/m^2K$); ground floor has outer rendered block skin around a timber frame with 150mm insulation (u value of $0.15W/m^2K$). Timber frame. - Roof: 120mm insulation between rafters and 65mm over - Floor: 165mm underfloor insulation (u value of $0.11W/m^2K$) - Windows: High performance double glazing with timber frames - Sealing around windows and taping joints to achieve airtightness (3.3 m3/hr/m2) **Heating and hot water** - Heating and hot water from $6m^2$ of solar thermal panels in summer and autumn - Heating and hot water from a 13kW wood burning stove with back boiler in winter - Air source heat pump (ASHP) (9kW) as back up for solar panels and stove - Solar PV panels (3.5kWp) to offset electricity required for ASHP - Underfloor heating **Other** - Low-energy lighting and appliances - Shading and solar blinds used to avoid overheating in the summer - Use of natural building and decorating materials - Rainwater harvesting for use in WCs and washing machine - Bat and bird boxes - A bike shelter - Outside washing lines	Designed to Level 5 of Code for Sustainable Homes[i]. At the time of interviews, the occupants had not lived in the house for a full year yet and had limited energy usage data available.
Hartington Road	- Terraced house - 2 bedrooms - $80m^2$ - New self-build during 2010-2012	**Building fabric and windows** - Walls: Timber frame with cavity walls, totalling 140mm of insulation (u value $0.18W/m^2K$) - Roof: plywood/ thermal laminate construction board - Floor: 120mm underfloor insulation - Windows: High performance double glazing with timber frames - High airtightness **Heating and hot water** - Hot water from solar thermal (12 high performance Evacuated tube solar collector) - Heating from a wood burning stove in winter if	Designed with Passivhaus[ii] aspirations, but given the site's location and budget, a full Passivhaus standard was not achievable. The house has an estimated 63% reduction in carbon emissions compared to an average UK home[iii].

		needed - Mechanical ventilation with heat recovery (MVHR) Other - Low-energy lighting and appliances - Passive solar gain - Sustainable and low embodied energy materials - Rainwater harvesting for WCs	
One Brighton	- 172 new apartments - 54 of the apartments are affordable - 1, 2 and 3-bedroom apartments - $925m^2$ community space - $1134m^2$ commercial space - Master plan approved for the site in 2003 with clear sustainability objectives - New build during 2007-2010	Building fabric and windows - Building frame: External walls with a reinforced concrete frame with 240mm insulating blocks. External cladding with 100mm wood fibre insulation boards. - Windows: High performance glazing - Sustainably sourced timber used throughout Heating and hot water - Communal heating system using a biomass boiler provides heating and hot water; gas boiler for back up - Ventilation system with heat recovery provides heating - Energy Services Company manages energy supply on the site Other - Low-energy lighting and appliances - Photovoltaic panels (9.4 kWp) - Roof top garden allotments - Rain-water harvesting used for irrigation of roof top garden - No private car parking, only nine spaces for disabled users and five for car-clubs users - Recycled materials used in building materials (e.g. concrete and roof)	Under BRE EcoHomes assessment (superseded by Code for Sustainable Homes), One Brighton achieved 79.7% of available credits at design stage (the highest by an apartment building at the time). Post-construction evaluation yielded a score of 79.9, also the highest ever achieved. However, given issues with initial biomass heating, carbon emissions were higher than expected at design stage during the first few years of operation[iv]. Following a new biomass boiler, a 67% reduction in operational carbon emissions compared to the UK's existing housing stock has been reported, with potential to achieve an 89% reduction by 2020[v].
The Nook	- Detached house built in 1895 - 6 bedrooms - $177m^2$ - Retrofit during 2010-2011	Building fabric and windows - Walls: 120mm internal and 120mm external wall insulation (u value $0.15W/m^2K$) - Roof: Attic floor 100mm insulation between joists and 100mm insulation over the joists (u value $0.10W/m^2K$) - Floor: Ground floor 100mm insulation (u value $0.13W/m^2K$) - Windows: Triple glazed timber windows with aluminium cladding on the sides and rear of the house. Double-glazed windows on the front of the house due to planning requirements on a	The house's Standard Assessment Rating (SAP)[vi] improved from 33 to 82 points (100 represents zero energy) – this was equivalent to the house moving from F-rated to B-rated[vii] under the Energy Performance Certificate (EPC)[viii].

		Conservation Area. **Heating and hot water** - 4 evacuated tube solar thermal panels provide hot water - A-rated condensing boiler fitted as a back-up - Mechanical ventilation with heat recovery (MVHR) **Other** - Low-energy lighting and appliances	The Nook set a precedent in Brighton for acquiring planning permission for measures such as double glazing in a conservation area.
Southampton Street	- Terraced house built in 1860 - 3 bedrooms - 126m^2 - Retrofit during 2013	**Building fabric and windows** - Walls: External solid walls with 100mm insulation foam batts (u value 0.18W/m^{2}K) - Roof: Loft with 270mm insulation - Windows: Double glazing **Heating and hot water** - A-rated condensing boiler **Other** - Low-energy lighting and appliances	The owners reported a 35% reduction in gas consumption (daily average in May 2012 and April 2013 was 44.25 kWh, post retrofit works between May 2013 and April 2014 average daily gas consumption was 28.52 kWh)[ix]. Southampton Street is located in an area of planning restrictions and external solid wall insulation took careful design to acquire a planning permission.
Wichelo Place	- Terraced house built in 1867 - 4 bedrooms - 125m^2 - Retrofit during 2008-2009	**Building fabric and windows** - Walls: External wall 80mm insulation at the front of the house, external wall 100mm insulation at the back of the house, internal walls 40-100mm insulation on ground floor extension, internal walls 100-150mm insulation in loft extension - Roof: Loft with 150mm insulation, including 50mm insulation in eaves, 150mm insulation in dormer - Floor: Loft conversion floor with 200mm insulation, in two bedrooms floors with 75mm insulation - Windows: double glazing **Heating and hot water** - Oversized evacuated solar thermal tube collectors - Wood burning stove (k5kW) **Other** - Low-energy lighting and appliances - Natural paints and materials used throughout	65% reduction in carbon emissions compared to an average UK home[x].

References and notes on Table A1:

[i] The Code for Sustainable Homes was launched in the UK in 2007 as an environmental assessment method for rating and certifying new homes in terms of Energy and CO^2 emissions, water, materials, surface water run-off, waste, pollution, health and wellbeing, management and ecology. The Code Level 6 was the highest, and most efficient, level of the Code, though very limited number of properties achieved that standard. The Code also allowed councils to adopt their own sustainability levels as a planning requirement for new residential development. However, the Code was removed by government in March 2015.

[ii] The Passivehaus standard aims to reduce the need for space heating and cooling. Online: http://www.passivhaus.org.uk [Accessed 09.05.2018].

[iii] Eco Open Houses. Case Study. 148 Hartington Road, Brighton BN2 3PB. Online: http://www.ecoopenhouses.org/media/Case%20study%20-%20148%20Hartington%20Road.pdf [Accessed 09.05.2018].

[iv] Good Homes Alliance. (2014). One Brighton, Building performance evaluation. Online: http://www.goodhomes.org.uk/downloads/members/gha-case-study-one-brighton-full.pdf [Accessed 09.05.2018].

[v] Bioregional. One Brighton Impact Report 2007-2014. Online: https://www.bioregional.com/wp-content/uploads/2014/10/One-Brighton-Impact-Report.pdf [Accessed 09.05.2018].

[vi] SAP quantifies a building's performance for energy use, energy efficiency and carbon emissions. Online: https://www.gov.uk/guidance/standard-assessment-procedure [Accessed 09.05.2018].

[vii] Project profile, The Nook, eco-retrofit of a Victorian house in multiple occupation. Online: http://www.ecoopenhouses.org/media/The%20Nook%20project%20profile.pdf [Accessed 09.05.2018].

[viii] An EPC is required when a dwelling is sold or rented, and it outlines energy performance and recommendations for improvements. Online: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/certificates-and-inspections [Accessed 09.05.2018].

[ix] Source: personal communication and energy data from the owners.

[x] Eco Open Houses. Case study. 4 Wichelo Place, Brighton, BN2 9XF. Online: http://www.ecoopenhouses.org/media/CaseStudies2015/Case%20study%20-%204%20Whichelo%20Place.pdf [Accessed 09.05.2018].

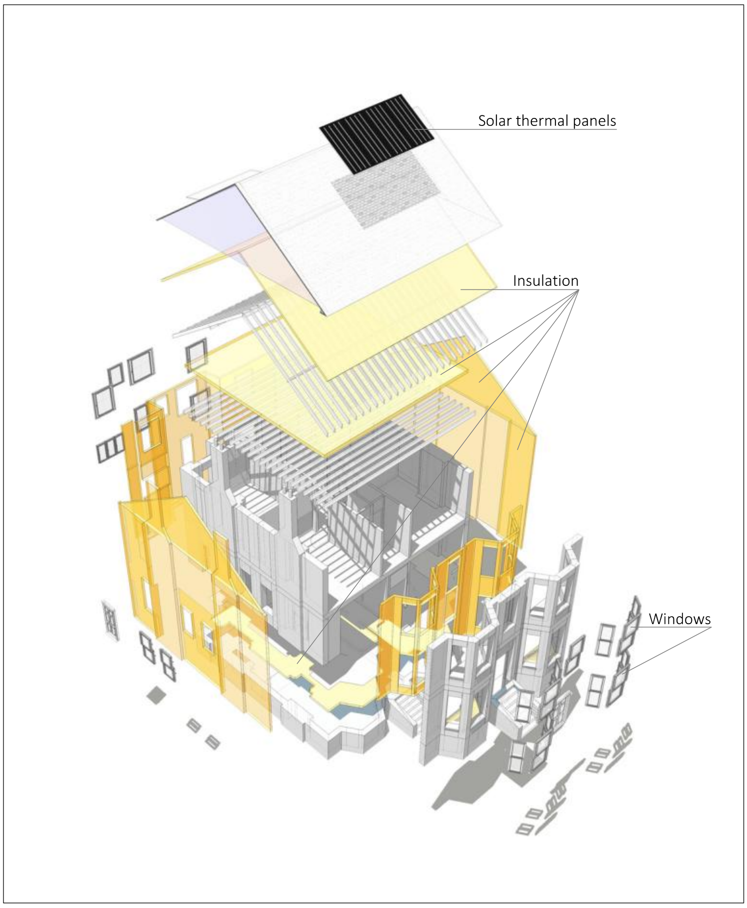


Figure A1: Example of different components in a retrofit project, The Nook (figure credits: BBM Sustainable Design Ltd.)

Figure A2: Example of different components in a new build project, Hartington Road (figure credits: Jason Thawley, Luminair)